Estimate Valve Pressure Drop Correctly

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Introduction

Valves are one the essential parts of any hydraulic system. They are used for stopping and starting flow, controlling flow rate, diverting flow, preventing back flow, isolation, throttling and mixing. Performing theses duties, they will cause some pressure drop. Valve head loss can be calculated using below equation:

$$\Delta h = K_1 \frac{V_1^2}{2g} = K_2 \frac{V_2^2}{2g}$$

Where V_1 and V_2 are fluid velocity at D_1 (valve bore, port or seat diameter) and D_2 (inlet/outlet flange or pipe diameter) respectively. If D_1 is equal to D_2, valve is called full bore, full port or full bore seat depending on type of valve (refer to the Figure 1).

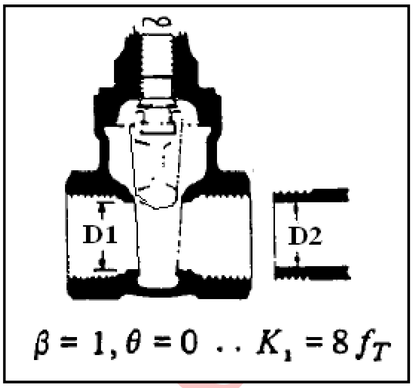


Figure 1 - Full Port Gate Valve

This note presents published K data for full bore valves in wide open condition and introduces a method for estimating reduced bore/port/ seat valves.

Full Bore

The resistance coefficients (K) for full bore/port/seat valves are presented in many hydraulic handbooks in different forms. The values in Table 1 have been extracted from Crane TP-410 which can be used along with following formula:

$$K_1 = K_2 = K' f_T$$

The schematic representations of the valves listed in this table are also depicted in figures 2 to 13 in following pages for easy reference.

Reduced Bore

- **Ball, Gate and Plug Valves**

Reduced bore/port requirement for ball, gate and plug valves are normally achieved by smaller bore on the valve ball/disc/plug and inlet and outlet portion of valve body through which reduction from valve inlet nozzle size to bore size takes place. In first look, it is seems impossible to produce a single correlation which can correctly predict pressure drop for such a wide variety, especially because of number of valve types, their different internal configurations, plug, seat and stem details, end connection types, their different effects on flow direction and flow passage, etc. For example ball valve can be split body, top entry, uni-body or end-entry (two-piece) with respect to access to the internals only.

In spite this complexity; Crane TP-410 introduces a simple correlation for estimating the resistance coefficient of this group of valves:

$$K_{\text{reduced bore}} = K_{\text{full bore}} + K_{\text{reducer}} + K_{\text{expander}}$$

Table 1 – Valve K′ Coefficient

Type of Valve		K'
Ball	Full bore (β = 1)	3
Gate	Full port (β = 1)	8
Plug	Full port - Straight way	18
	Full port - Three way- Flow straight	30
	Full port - Three way- Flow through side	90
Globe	Full bore seat - Straight (std) pattern	340
	Full bore seat - Y (45° oblique) pattern	55
Angle	Full bore seat - Flat (conventional) seat	150
	Full bore seat - Tapered seat	55
Check	Full bore seat - Swing type - inclined seat	100
	Full bore seat - Swing type - vertical seat	50
	Full bore seat - Piston type - inclined seat	55
	Full bore seat - Piston type- horizontal	600
	Tilting disc type – 2” to 8”	120
	Tilting disc type – 10” to 14”	90
	Tilting disc type – 16” to 48”	60
Butterfly	Single offset - 2” to 8”	45
	Single offset - 10” to 14”	35
	Single offset - 16” to 24”	25
	Double offset - 2” to 8”	74
	Double offset - 10” to 14”	52
	Double offset - 16” to 24”	43
	Triple offset - 2” to 8”	218
	Triple offset - 10” to 14”	96
	Triple offset - 16” to 24”	55
Diaphragm	Weir (Dam) type	149
	Straight through type	39
Foot valve with mesh	Poppet Disc type	420
	Hinged Disc type	75

According to this equation, reduced bore valve pressure drop is nothing but pressure drop of full bore valve plus pressure drop of fluid expansion and contraction associated with bore size reduction. Resistance coefficient for reducing and expanding sections of the valve also can be calculated by using of the equations presented in the same reference (refer to Table 2).

Table 2 – Reducer and Expander Resistance Coefficient Calculation

Contraction	**Expansion**
$\theta \le 45^o$ $K_1 = 0.8\left(1-\beta^2\right)\left(\sin\frac{\theta}{2}\right)$	$\theta \le 45^o$ $K_1 = 2.6\left(1-\beta^2\right)^2\left(\sin\frac{\theta}{2}\right)$
$45^o < \theta < 180^o$ $K_1 = 0.5\left(1-\beta^2\right)\left(\sin\frac{\theta}{2}\right)^{0.5}$	$45^o < \theta < 180^o$ $K_1 = \left(1-\beta^2\right)^2$

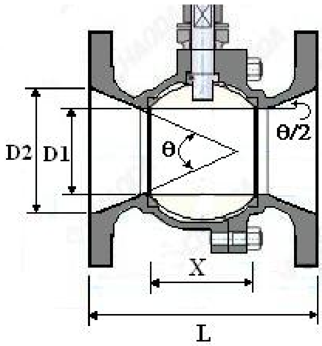
Where

θ : reducer/expander angle

β : ratio of bore diameter to flange diameter

$$\beta = \frac{D_1}{D_2}$$

$$K_2 = \frac{K_1}{\beta^4}$$



The only problem is that Crane does not specify valve reducer and expander angle which makes user take full bore valve resistance coefficient instead of reduced bore. Doing some mathematical homework, following equation is obtained:

$$\frac{\theta}{2} = \text{Tan}^{-1}\left[\frac{(D_2 - D_1)/2}{(L - X)/2}\right]$$

Where L and X are total length of valve and distance occupied by ball, disc or plug. Both of these parameters are unknown to process engineer who is going to do hydraulic calculations which can be extracted from valve vendor catalogue.

The dimensions of flanged and welded valves are available in ASME B16.10, “Face-to-Face and End-to-End Dimensions of Valves”. In absence of vendor data, this standard can be used to get the total length of valve. Using the same standard and regression techniques, I produced below equation that can be used for programming purpose:

$$L = \left(a + b\,D^{0.5}\right)^2$$

Where a and b are constant figures shown in Table 3. L and D are valve total length and nominal valve size in mm, respectively.

Based on data available in different valve vendor catalogues, I could define X dimension as a percentage of total length of valve (L).

Table 3 – Standard Valve Length Coefficients

Valve Rating	**a**	**b**
150	8.95	0.575
300	5.81	1.168
600	8.05	1.219
900	9.88	1.196
1500	8.80	1.434
2500	9.50	1.645

Table 4 – Ball, disc and plug size

Valve Type	**X**
Ball	
$< 2”$	0.3 L
$\ge 2”$	0.5 L
Gate	0.25 L
Plug	0.5 L

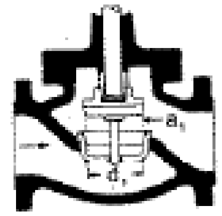


Figure 2 - Straight pattern globe valve

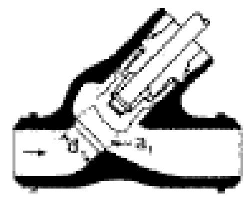


Figure 3 - Y pattern globe valve

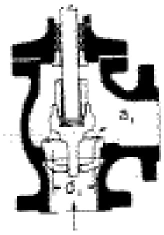


Figure 4 - Flat seat angle valve

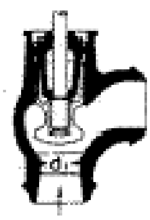


Figure 5 - Tapered seat angle valve

Figure 6 – Inclined seat swing check valve

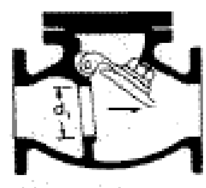


Figure 7 - Vertical seat swing check valve

- **Globe, Angle and Check Valves**

For reduced seat globe, angle and piston and swing check valves, the equation presented in note "Contraction, Expansion, Pressure Drop" can be utilized.

- **Butterfly, Diaphragm and Foot Valves**

Reduced bore term is not applied to this group of valves so resistance coefficient reported in Table 1 can be used for this category without any manipulation.

Case Study

For 6" x 4", 150 lb reduced bore ball valve; the resistance coefficient can be calculated as follow:

From Table 1, for 6" full bore ball valve, K_1 is equal to $3f_T$ where $f_T = 0.015$ therefore:

$K_{1,\text{full bore}} = 3 \times 0.015 = 0.045$

For 6" (150 mm) ball valve, $L = (8.95 + 0.575 \times 150^{0.5})^2 = 255$mm and $X = 0.5 \times 255 = 128$mm.

Therefore

$$\frac{\theta}{2} = \mathrm{Tan}^{-1}\left[\frac{(150-100)/2}{(255-128)/2}\right] = 21.5°$$

From Table 2, for reducer:

$$K_{1,\text{reducer}} = 0.8\,(1 - 0.67^2)\,\mathrm{Sin}\,(21.5) = 0.16$$

And for expander:

$$K_{1,\text{expander}} = 2.6\,(1 - 0.67^2)^2\,\mathrm{Sin}\,(21.5) = 0.29$$

So resistance coefficient for reduced bore ball valve will be:

$K_1 = 0.045 + 0.16 + 0.29 = 0.49$

K_1 can be used along with velocity at bore (V_1) to calculate valve pressure drop.

Since fluid velocity at pipe/valve flange (V_2) is normally calculated during hydraulic calculations, user may prefer to calculate K_2 from beginning. For this purpose, the only required change is to divide above calculated K_1 by β^4.

For above example, $K_2 = 0.49/0.67^4 = 2.43$

In this particular example, resultant K_2 is in good agreement with the result of simple method proposed in note "Contraction, Expansion, Pressure Drop".

Contact

Please visit www.linkedin.com/groups/Chemwork-3822450 should you have any comment, question or feedback or feel free to contact S.Rahimi@gmail.com.

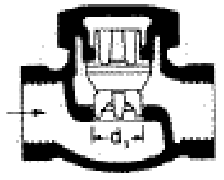


Figure 8 - Piston check valve – horizontal seat

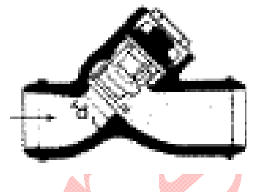


Figure 9 - Piston check valve – inclined seat

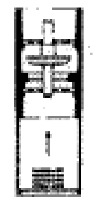


Figure 10 - Poppet disc foot valve

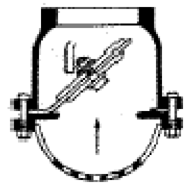


Figure 11 - Hinged disc foot valve

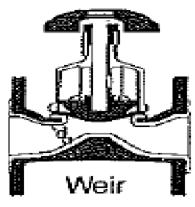


Figure 12 - Weir type diaphragm valve

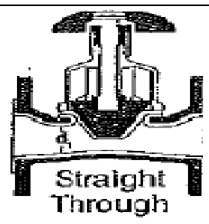


Figure 13 - Straight through type diaphragm valve